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CALCULATION OF THE RESPONSE OF ADAPTION KITS IN ACCIDENTAL SIDE--ETC(U)
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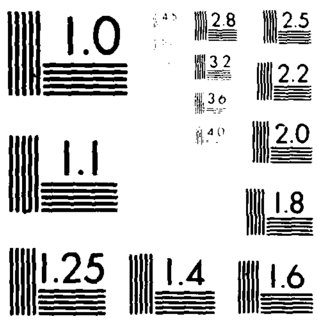

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

July 1980

Bimonthly Progress Report No. 13
~~Covering the Period~~ 3 May 1980 ~~through~~ 2 July 1980

CALCULATION OF THE RESPONSE OF ADAPTION KITS
IN ACCIDENTAL SIDE IMPACTS

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I INTRODUCTION

This report is the thirteenth bimonthly progress report covering SRI International's current study of the response of adaption kits in accidental side impacts. The primary goal of the project is the further development of finite element models for a generic missile structure so that adaption kit response, particularly component accelerations, can be predicted for side impacts of the missile. An additional goal is experimental determination of the impact response of a missile structure that contains a hard link safe-arm device.

The work planned for this contract consists of five tasks. In Task 1, we are further developing finite element models for substructures and checking the models' predictions against experimental data. In Task 2, we are using the models to calculate the response of complete structures, again by comparing the predictions with experimental results insofar as feasible. In Task 3, we are transferring the analytical capabilities developed in Tasks 1 and 2 by implementing the SUPER code at AARADCOM. In Task 4, we are performing impact experiments on scale models of a specific prototype missile structure to help plan some full-scale tests. In task 5, we are developing a new bolt element for use in three-dimensional calculations. For a more detailed description of Tasks 1 through 3, refer to Bimonthly Progress Report No. 1, July 1978. Task 4 is described fully in Bimonthly Progress Report No. 3, November 1978. Task 5 has only recently been added and is described more fully in the next paragraph.

Task 5 is to develop a new bolt element for use in three-dimensional calculations. The new bolt element will allow the SUPER finite element code to predict the response of adaption kits in side impacts in which plate-bending occurs. The bolt element developed previously can be used only for calculations of in-plane response because it transmits only in-plane forces. The new bolt element will use a nonlinear spring with modifications for unloading and for breaking. The bolt element formulation will be included in the final verson of the SUPER code, which will be delivered to AARADCOM.

II PROGRESS

The new bolt element (Task 5) was developed during this reporting period.

Bolt Element Configuration

The purpose of the bolt elements used in the SUPER calculations is to simulate bolt shearing and bolt hole stretching with a single element. Standard elements are used, but the material properties of these elements are chosen so that the shear force versus shear displacement relation of the bolt element approximates the results of static lap shear tests.

The new bolt element is modeled with a nonlinear spring that transmits only axial force. Figure 1 shows the layout of the bolt element for modeling bolts that attach the AK plate to the ring. (The bolt element can also be used to model bolts that attach AK components to the AK plate.) The horizontal component of the axial force in the spring element represents the in-plane shear force that is transmitted between the plate and ring (or between the plate and the AK components). The relative motion between the plate and the ring due to impact will produce a relative horizontal displacement d at the ends of the spring element as shown in Figure 2(a). This relative displacement results in an axial stretch in the spring element, as shown in Figure 2(b). Associated with this axial stretch is an axial force that has a horizontal component. The relationship between the axial force and axial stretch is chosen so that the horizontal force versus horizontal displacement approximates the results of the lap shear tests.

SUPER Nonlinear Spring

The finite element used for the bolt is a nonlinear spring. Figure 3 shows the axial force $N = f(\Delta\ell)$ versus change in length $\Delta\ell$ for a general nonlinear spring. In the SUPER code, this curve is approximated by three

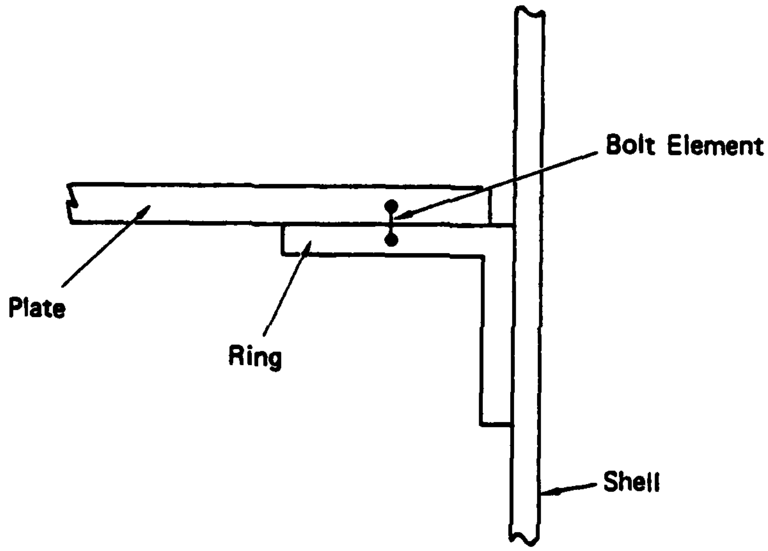

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FIGURE 1 BOLT ELEMENT MODEL

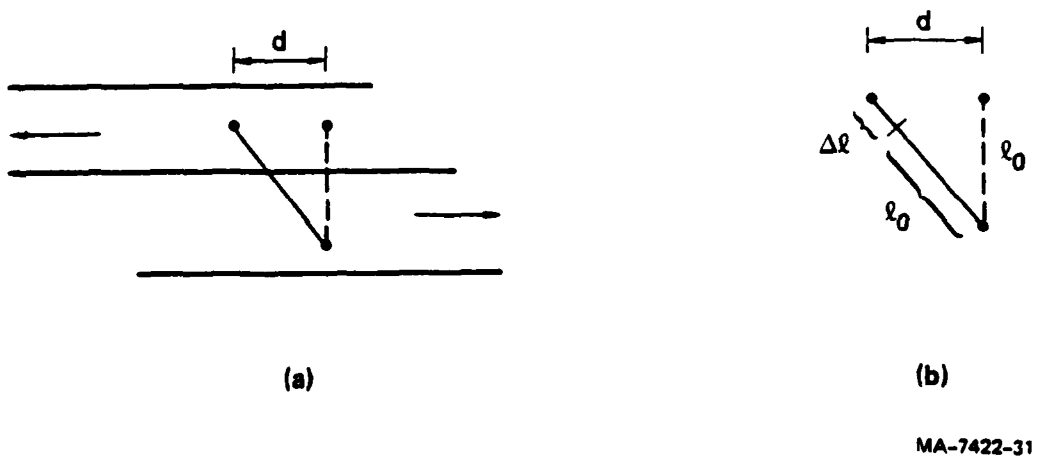

FIGURE 2 RELATIVE DISPLACEMENT PRODUCED AT THE ENDS OF THE SPRING BY IMPACT MOTION

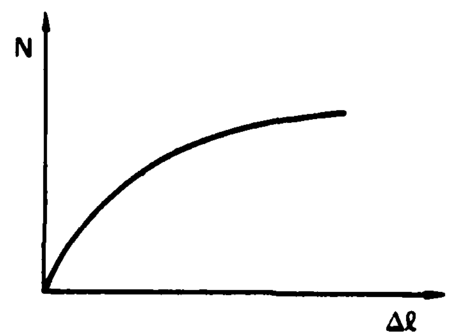

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FIGURE 3 AXIAL FORCE-DISPLACEMENT FOR A NONLINEAR SPRING

straight line segments as in Figure 4. The slopes of the straight lines are the stiffnesses of the spring. The total axial force in the spring between $\Delta\ell_i$ and $\Delta\ell_{i+1}$ is given by

$$N = [\sum_i K_i(\Delta\ell_i - \Delta\ell_{i-1})] + K_{i+1}(\Delta\ell_{i+1} - \Delta\ell_i)$$

Figure 5 shows the force and displacement of the bolt element. In the figure, ℓ_o is the initial length of the element, d is the relative horizontal displacement of the ends of the element, N is the axial force, F is the horizontal component of the axial force, and θ is the angle of rotation of the element from its original position. The change in length $\Delta\ell$ is given by

$$\Delta\ell = \sqrt{d^2 + \ell_o^2} - \ell_o$$

The axial force is a function of $\Delta\ell$ as indicated by

$$N = f(\Delta\ell)$$

The horizontal component of N is

$$\begin{aligned} F &= N \sin\theta \\ &= f(\Delta\ell) \sin\theta \end{aligned}$$

where

$$\sin\theta = \frac{d}{\sqrt{d^2 + \ell_o^2}}$$

As indicated in Figure 4, the spring element in the SUPER code can have three stiffnesses. Thus, equations for horizontal force F versus horizontal relative displacement d are, in general:

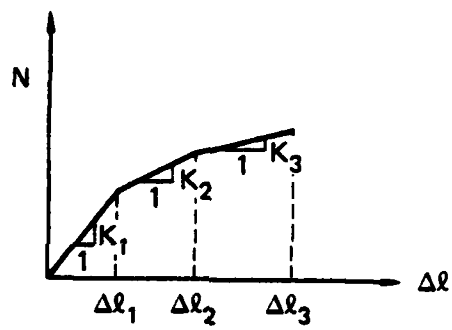

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FIGURE 4 STRAIGHT-LINE APPROXIMATION OF AXIAL FORCE-DISPLACEMENT FOR A NONLINEAR SPRING

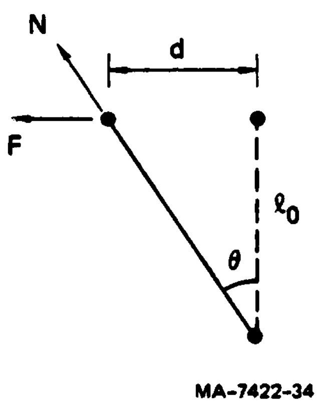

FIGURE 5 AXIAL FORCE-DISPLACEMENT DIAGRAM FOR BOLT ELEMENT

$$F = \begin{cases} K_1(\sqrt{d^2 + \ell_o^2} - \ell_o) \sin\theta & \text{for } \Delta\ell < \Delta\ell_1 \\ [K_1\Delta\ell_1 + K_2(\sqrt{d^2 + \ell_o^2} - \ell_o - \Delta\ell_1)] \sin\theta & \text{for } \Delta\ell_1 \leq \Delta\ell < \Delta\ell_2 \\ [K_1\Delta\ell_1 + K_2(\Delta\ell_2 - \Delta\ell_1) + K_3(\sqrt{d^2 + \ell_o^2} - \ell_o - \Delta\ell_2)] \sin\theta & \\ & \text{for } \Delta\ell_2 \leq \Delta\ell < \Delta\ell_3 \end{cases}$$

Loading Characteristics

The lap shear test results suggest that the horizontal component of the axial force versus horizontal displacement resembles a sine function of the form

$$F = A \sin\phi$$

where A is an arbitrary constant and ϕ is a parameter in the range $o \leq \phi \leq \pi/2$. Thus, a good approximation to the test results may be obtained by using a spring with a constant axial force N_1, so that

$$F = N_1 \sin\theta$$

Since the spring element is governed by stiffnesses rather than by forces, we use a spring with an initial stiffness K_1 up to a constant force N_1 and K_2, K_3 equal to zero. Choosing $K_1 = 790{,}866$ N/mm, $\ell_o = 0.381$ mm, $\Delta\ell_1 = 0.00132$ mm gives a good fit to the lap shear data.

Referring back to the equations for the horizontal force, we have

$$F = K_1(\sqrt{d^2 + \ell_o^2} - \ell_o) \sin\theta \qquad \text{for } \Delta\ell < 0.00132 \text{ mm}$$

$$F = K_1\, \Delta\ell_1 \sin\theta \qquad \text{for } \Delta\ell \geq 0.00132 \text{ mm}$$

and

$$N_1 = K_1\, \Delta\ell_1 = 1044 \text{ N}$$

Figure 6 shows the axial force–change in length relationship for the spring element. A plot of the shear force versus shear displacement for the bolt element model and the lap shear test results is shown in Figure 7.

Unloading Characteristics

Figure 8 shows the axial force, its horizontal component, and the relative displacement of the bolt element under unloading; d_1 and d_2 are any two points along the unloading curve of the bolt element and $d_1 > d_2$. The change in length of the spring element is given by

$$\Delta\ell_u = \sqrt{d_1{}^2 + \ell_o{}^2} - \sqrt{d_2{}^2 + \ell_o{}^2}$$

Provided the spring is not loaded beyond the rupture point, the change in axial force ΔN associated with the change in length $\Delta\ell_u$ is assumed to be linear, given by

$$\Delta N = K_u \, \Delta\ell_u$$

where K_u is the coefficient of stiffness for unloading of the spring element. The horizontal component of the axial force is

$$F = (N - \Delta N) \sin \theta$$

$$F_1 = N \frac{d_1}{\sqrt{d_1{}^2 + \ell_o{}^2}}$$

$$F_2 = (N - \Delta N) \frac{d_2}{\sqrt{d_2{}^2 + \ell_o{}^2}}$$

A spring element with $K_u = 8584$ N/mm will give us an unloading curve for the horizontal component of the axial force versus relative horizontal displacement that matches the experimental results. A comparison of the bolt element model with the lap shear test result for both loading and unloading was shown in Figure 7.

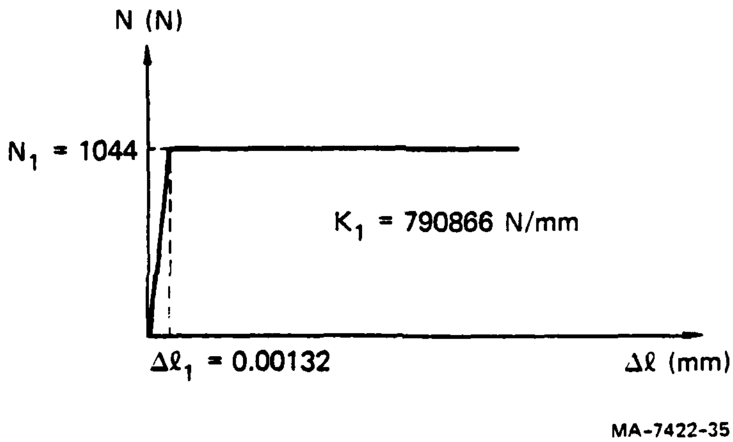

FIGURE 6 AXIAL FORCE-CHANGE IN LENGTH RELATIONSHIP FOR THE SPRING ELEMENT

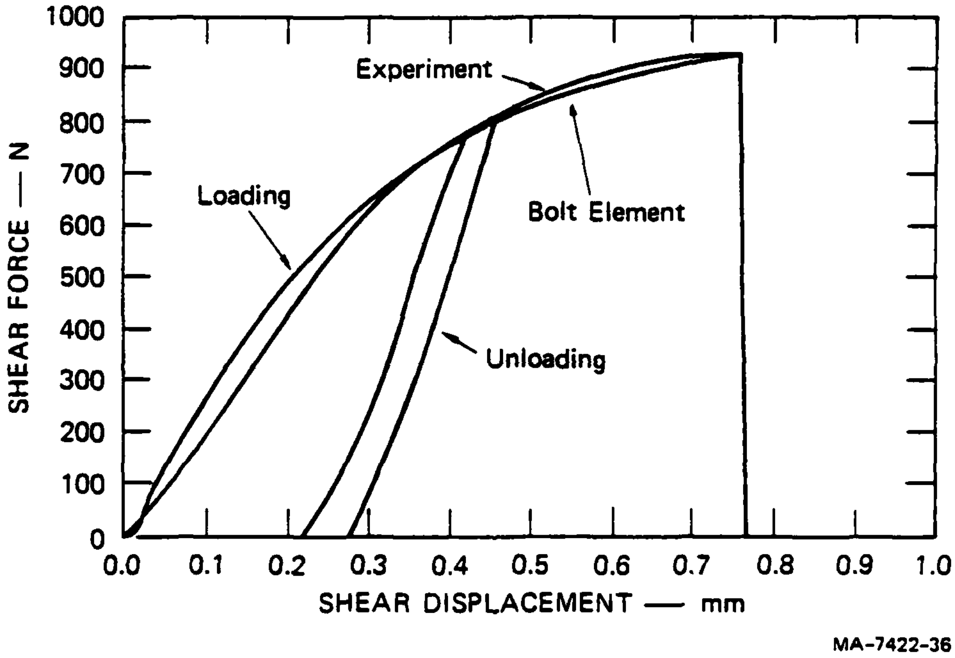

FIGURE 7 BOLT ELEMENT MODELED AS A NONLINEAR SPRING

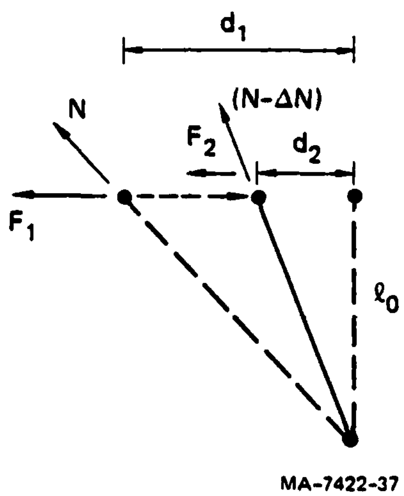

FIGURE 8 FORCE-DISPLACEMENT RELATIONSHIP OF THE BOLT ELEMENT UNDER UNLOADING

III FUTURE WORK

During the next reporting period, a SUPER calculation of a three-dimensional multicomponent structure will be conducted. The calculation will test the adequacy of the new bolt element for use in calculations involving plate bending. The results of the calculation will also be compared qualitatively with an experiment on a complete missile section.

IV FINANCIAL STATUS

As of 27 June 1980, $84,500 has been spent on labor (1671 supervisory and professional hours, 968 technical and clerical hours), and $11,631 has been spent on materials and services. Of the total contract funds ($98,435), the balance remaining is $2,304. A performance and cost report for this period is attached.

PERFORMANCE AND COST REPORT
DAAK-10-78-C-0158
PYU-7422 - Report No. 13

Reporting Period: 3 May 1980 - 2 July 1980

Hours

Total hours expended to date:

Supervisory and Sr. Professional Personnel	275
Professional Personnel	1396
Technician and Clerical	968
Cumulative total hours to date	2639
Percent of total hours expended to date	98%

Funds

Funds expended during the reporting period	$ 2,235
Funds expended to date	$96,130
Percent of total funds expended to date	98%

Work

Percent of work completed during the reporting period	3%
Percent of work completed to date	98%